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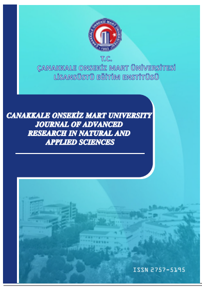

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Orbital Period Changes of Selected Two Semi-Detached Binaries

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Research Article

Abstract − Since the data obtained from satellite data are very sensitive, the minima times of the target systems have obtained from Kepler (K2) and TESS observations. A total of 14 minima times were obtained from Kepler (K2) data for the AF Gem system and 11 minima times in two different sectors from the TESS data for the RY Gem system. In this study, orbital period behaviours of semi-detached binaries (SDBs) AF Gem and RY Gem systems have investigated, together with minima times obtained from literature and satellite data. It has been observed that the orbital periods of AF Gem and RY Gem decrease. The period change rates of AF Gem and RY Gem systems are determined as dP/dt = -4.1×10-8 and $dP/dt = -6.5\times10^{-6}$ day/yr. The magnetic activity of the systems' cooler components may be the cause of the periods' decrease, and so the mass loss rates of the systems have been estimated. For AF Gem and RY Gem, mass loss rate was found to be -4.4×10^{-8} $M_\odot$/yr and -8.2×10^{-7} $M_\odot$/yr, respectively. In the O-C graph of AF Gem, sinusoidal changes also exist. A tertiary body around the eclipsing pair can be used to depict a sinusoidal variation caused by a light time effect (LITE). The minimum mass of a possible third star in the vicinity of AF Gem has been determined to be 0.24 $M_\odot$.

Keywords − *AF Gem, O-C analysis, Orbital period changes, RY Gem, Semi-detached binaries (SDBs).*

1. Introduction

Kopal (1959), divided the eclipsing binaries into three subclasses according to the Roche classification as detached, semi-detached and contact stage. Classical Algol binaries are generally in the class of close binaries systems and they are semi-detached structure. One of the components of such systems has filled the Roche lobe while the other has not. The component with more mass and not filling the Roche lobe is usually of the B-A spectral type. The component with less mass and filling the Roche lobe is of the F-K spectral type giant or sub-giant class. In such systems, the less component that filled the Roche lobe transfers mass to the other component. If there is the mass transfer between components (from less component to other component), the period of the system will show increasing parabolic change. However, mass loss from the system will cause to decrease the period of the system. Some semi-detached systems also provide evidence of magnetic activity (e.g Retter et al. 2005, Soydugan et al. 2007). The analysis made by subtracting the calculated time from the observed time is the *O-C* analysis, and this method is the most widely used method to examine the orbital period change. It is important to study orbital period variation because it contains information about the evolution of stars. For this reason, an important study on the orbital period changes of such systems has made by Erdem and Öztürk (2014), and the mass loss rates of some systems have estimated. In this study, the orbital period changes of the selected semi-detached AF Gem and RY Gem systems have investigated. The orbital period analysis study of these two semi-detached systems is included in the literature, but this study supports the studies in the literature by calculating the minima times from the satellite data. Since the periods of the systems are relatively long (especially the RY Gem system), the minima times calculated from the satellite data make a significant contribution to the literature, and this is also very important for the *O-C* analysis.

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The eclipsing binary system AF Geminorum (GSC 01343-02855, TYC 1343-2855-1, Gaia DR2 3378297756072107392, V=10^{m}.82) is a semidetached classical Algol. Photographic light curve has published by Guthnick and Prager (1928) and light curve analysis has done by Gaposchkin (1932). The first photoelectric light curve (in *UBV* filters) was acquired by Chambliss (1982). The radial velocity curve and its analysis has made by Maxted and Hilditch (1995) and the mass ratio of the AF Gem has determined as q = 0.342 and the components' spectral type has also been found as B9.5V + G0IV in the same study. Light curve in BVRI filters of the AF Gem system has obtained by Yuhas et al. (2013). The existence of a possible third object in the system and the decrease of the period have suggested by Yuhas et al. (2013). The orbital period analysis of AF Geminorum has made by Yang et al. (2014) and Tvardovskyi (2019). In both studies, it was seen that both the period decreased and there was a cyclical change.

Semi-detached RY Gem (GSC 01347-00922, TYC 1347-922-1, Gaia DR2 3168597794613114240, V=8^{m}.68) was discovered by Huang and Struve (1956). Photoelectric light measurement in UBV filters of the RY Gem system has obtained by Kalv (1980). A detailed photoelectric study in UBV filters was carried out by Hall et al. (1981). In the same study, it was reported that the second component of the RY Gem was cold and a semi-detached system filling the Roche lobe. Some of the most fundamental physical parameters of the RY Gem system, such as mass, radius, have reported by Sarma and Vivekananda (1997). It has also stated in the same study that the spectral type of the system is A2V+K0-3IV-V. The orbital period analysis of the system has carried out by Pustylnik et al. (2005) and Erdem and Öztürk (2014). Both studies have reported that the period of the system decreased. The orbital period decrease rate of the RY Gem system was reported by Erdem and Öztürk (2014) as -0.58 s/yr.

2. Materials and Methods

Minima times are of great importance for orbital period analysis. Therefore minima times have calculated from *Kepler* and *TESS* satellite data for the AF Gem and RY Gem systems. Observations of the AF Gem system have started in March 2014 by *Kepler* (K2) and continued until May 2014. Observations of the RY Gem system have started in January 2019 by *TESS* and continued in sector 7 until February 2019. And at the same time, observations of the RY Gem system have started by *TESS* in December 2020 and continued in sector 33 until January 2021. For the systems, the data received from the satellites have converted to normalized flux and light curves have created. The graph of light curves of AF Gem and RY Gem systems converted to normalized flux and plotted according to phase is given in Figure 1. The light curves have ordered by time and the minima times have calculated by dividing them into individual days. The minima times obtained from *Kepler* (K2) and *TESS* data have obtained by the Kwee van Woerden method (Kwee and van Woerden, 1956). The minima times obtained from the observations, along with their errors, are given in Table 1. The minima times calculated from Kepler (K2) data for the AF Gem have determined with an error in the range of 25 seconds to 430 seconds. For RY Gem, the minima times calculated from the data received from the TESS satellite in different years (2019, 2020-2021) have determined with error range of 8 seconds to 80 seconds. Information about the minima times of the systems collected from the literature and obtained from the satellite data is given in Table 2. This table has given the numbers of visual (v), photographic (pg), photoelectric (pe) and CCD data, as well as the first (Min I) and second minima (Min II) eclipse times.

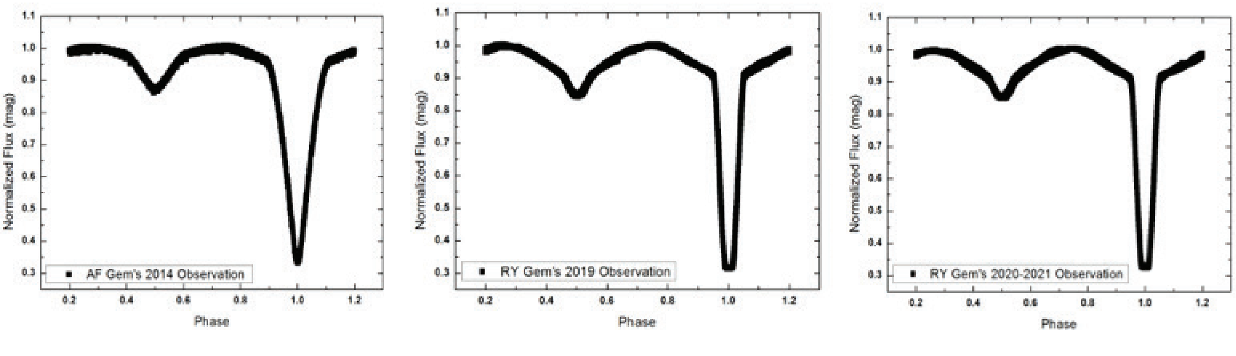

Figure 1. Graphs from left to right, AF Gem's Kepler (K2) 2014 observation, RY Gem's TESS 2019, 2020-2021 observations are shown (light curves have normalized to 1 and plotted between 0.2 and 1.2 phases).

To investigate the period variations of binary systems, the system's previously observed the *O-C* graph created with the minima times is use. Here, *O* (Observed); minima times previously observed and *C* (Calculated); represents the calculated minima times. The *O-C* graph is obtained when the difference between these two times is plotted versus the *E* (Epoch) values. The orbital period analysis of the selected systems were made with the help of the codes under MATLAB written by Zasche et al. (2009). The parabolic period changes of the systems are calculated by using the weighted least squares method using the MATLAB code written by Zasche et al. (2009). Since there is a cyclical change in the *O-C* diagrams, the light time effect (LITE) analysis was also performed using the same MATLAB code. Using the light elements of the system, the minima at any given time is given by Equation (2.1).

$$C = T = T_0 + E.P \tag{2.1}$$

In the Equation (2.1), T_0 is an initial minima time observed previously, *E* the epoch number and *P* (days) of the binary system represents the orbital period.

There are four reasons why the orbital period of a system can change. These are mass exchange between stars or loss of mass from the system, the period due to magnetic activity may change, possible presence of a third object and axis rotation. Equation (2.2) is used if the period of systems is increasing or decreasing.

$$\text{Min } I = T_0 + E.P + Q.E^2 \tag{2.2}$$

Q is the coefficient of the parabolic term (other terms are defined in Equation (2.1)). Equation (2.3) is used to calculate the period change rates.

$$\frac{\Delta P}{P} = \frac{2.Q}{P} \tag{2.3}$$

The unit obtained in Equation 2.3 used for the orbital period change is in days/day and then converted to desired unit type.

Light-time effect (LITE), sinusoidal on the *O-C* graph it is seen in the form of curve and this situation has equated by Irwin (1959) (Equation (2.4).

$$\Delta t = \frac{a_{12}\sin i'}{c}\left\{\frac{1-e'^2}{1+e'\cos v'}\sin(v'+w') + e'\cos w'\right\} \tag{2.4}$$

Δt is time delay. a_{12} is the semi-major axis. *i'* is inclination. *e'* is eccentricity. *v'* is true anomaly of the position of the binary system's mass center of orbit. *w'* is the longitude of the periastron of the orbit of the eclipsing binary around the third component.

Table 1

Minima times obtained from Kepler (K2) and TESS data for AF Gem and RY Gem.

System	**Minima Times (HJD+2400000)**	**Errors**	**Type (MinI/MinII)**	**Mission**
AF Gem	56769.4373	0.0038	II	Kepler(K2)
AF Gem	56770.6822	0.0010	II	Kepler(K2)
AF Gem	56771.3026	0.0012	I	Kepler(K2)
AF Gem	56779.3855	0.0010	II	Kepler(K2)
AF Gem	56781.2502	0.0003	I	Kepler(K2)
AF Gem	56785.6032	0.0031	II	Kepler(K2)
AF Gem	56786.2255	0.0021	I	Kepler(K2)
AF Gem	56786.8423	0.0016	II	Kepler(K2)
AF Gem	56791.1984	0.0051	I	Kepler(K2)
AF Gem	56791.8208	0.0020	II	Kepler(K2)
AF Gem	56801.1459	0.0035	I	Kepler(K2)
AF Gem	56801.7705	0.0020	II	Kepler(K2)
AF Gem	56803.6341	0.0041	I	Kepler(K2)
AF Gem	56804.2557	0.0012	II	Kepler(K2)
RY Gem	58496.2229	0.0004	II	TESS
RY Gem	58500.9155	0.0004	I	TESS
RY Gem	58505.5314	0.0003	II	TESS
RY Gem	58510.1893	0.0001	I	TESS
RY Gem	58514.8497	0.0005	II	TESS
RY Gem	59203.0809	0.0004	II	TESS
RY Gem	59207.7174	0.0001	I	TESS
RY Gem	59212.3727	0.0005	II	TESS
RY Gem	59217.0180	0.0001	I	TESS
RY Gem	59221.6526	0.0009	II	TESS
RY Gem	59226.3183	0.0001	I	TESS

Table 2

Statistical information about the minima times of the semi-detached systems (AF Gem and RY Gem) selected for analysis.

System	**Data Range (year)**	**Vis.**	**Pg.**	**Pe./ CCD**	**Kepler(K2) /TESS**	**Type Min I/ Min II**	**The total number of data**
AF Gem	~120	164	17	2/79	14	264/12	276
RY Gem	~120	20	5	17/5	11	52/6	58

A second way for cyclical changes in *O-C* graphs is described by Applegate (1992). In this mechanism of Applegate, oscillations in orbit are suggests that is the result of magnetic activity in one or both components. *O-C* changes because of magnetic cycle are cyclical and can be described by Equation (2.5).

$$\text{Min } I = T_0 + E.P + A_{mod} \sin\left[\frac{2\pi}{P}(E - T_s)\right] \tag{2.5}$$

A_{mod} is the amplitude. P_{mod} is period. T_s is minimum moment of the cyclic change. Data information used in *O-C* analysis of the systems studied is given in Table 2. The *O-C* gateway (Paschke and Brat, 2006) provided the majority of the data used in the investigation. Some basic physical parameters used in *O-C* analysis of target systems are given in Table 3.

Table 3

Basic physical parameters of systems used in analysis.

Parameters	**AF Gem**	**RY Gem**	**Ref.**
Spectral type	B9.5V+G0 III-IV5	A2V+K0-3 IV-V12	1,2
P (day)	1.24350021918	9.30068918	3
T_0 (HJD+2400000)	27162.319418	39732.615818	3
M_1-M_2 ($M_\odot$)	3.37-1.155	2.04-0.3912	1,2
R_1-R_2 ($R_\odot$)	2.61-2.325	2.38-6.1912	1,2

References: 1: Maxted and Hilditch (1995), 2: Sarma and Vivekananda (1997), 3: Kreiner (2004)

3. Results and Discussion

In this study, 14 and 11 minima times have obtained for AF Gem and RY Gem systems from *Kepler* and *TESS* satellite data, respectively. The orbital period analysis study of the systems has carried out with the minima times collected from the literature and the ones obtained from the satellite data. The orbital period study of the AF Gem eclipsing binary has performed with minima times of 276 and a data spanning over approximately 120 years. The period of the AF Gem is decreasing and cyclical change is also observed (see Figure 2 and Figure 3). While Yang et al. (2014) found the period decrease rate of the system as −5.59 (±0.39)10^{-8} d/yr, it has been found as -4.1×10^{-8} d/yr in this study. In semi-detached binaries, the second component filled the Roche lobe while the first component did not the Roche lobe, so mass and energy are transferred from the second component to the first component. (e.g Retter et al. 2005, Soydugan et al. 2007). In this case, the period of the systems increases, but the period of the AF Gem system is decreasing. Therefore, the period decrease reason of the AF Gem system is suggested as the loss of mass from the system and the estimated loss rate is given in Table 4. Cyclical change is explained in two ways. The first of these is explained by the Applegate (1992) mechanism, but the quadrupole moment of the second component was obtained as 1.6 10^{50} g cm^2 and this value is not in the range suggested by Lanza and Rodono (2002). Therefore, the possible existence of a third object in the system, which is the second way, has emphasized. The period analysis of the RY Gem system with 58 minima times has performed over a data interval of approximately 120 years. Period of RY Gem is decreasing (see Figure 4). While Erdem and Öztürk (2014) calculated the period decrease rate of the RY Gem system as -0.58 s/yr, it was calculated as -0.55 s/yr in this study. The reason for the RY Gem system's orbital period decreasing is the same as that of the AF Gem.

Table 4

The parameters that was found from the *O-C* analysis for the AF Gem and RY Gem.

System	**AF Gem**	**RY Gem**
T_0 (HJD+2400000)	52501.1265(6)	39732.6410(16)
P_{orb} (day)	1.2434988 (1)	9.3005962 (15)
Q (day)	-0.7 (1)10^{-10}	-823 (42)10^{-10}
dP/dt (s/cn)	-0.36	-55
dM/dt (mass loss) ($M_\odot$/yr)	-4.4$10^{-8}$	-8.2 10^{-7}
A (day)	0.0083(6)	---
a_{12} sin i (AB)	1.48 (11)	---
e	0.23 (11)	---
ω (deg)	6 (1)	---
T′ (HJD+2400000)	55609 (874)	---
P_{12} (yr)	73 (3)	---
$f(m_3)$ ($M_\odot$)	0.00061 (1)	---
m_3 ($M_\odot$) (for i=90°)	0.24	---

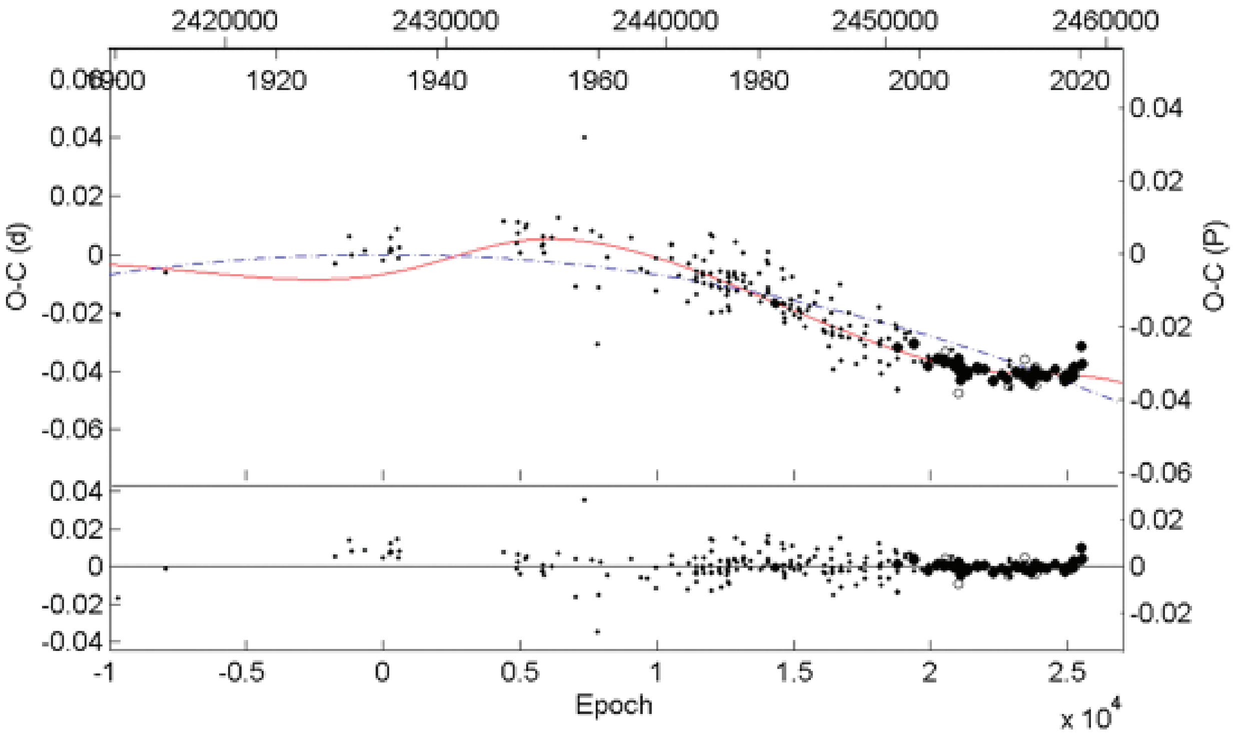

Figure 2. Distribution of AF Gem's *O-C* data and its representation with theoretical curves. The dashed line is parabolic, the continuous one is the theoretical curves calculated using the terms parabolic and LITE together. The bottom panel shows the differences from the continuous theoretical curve.

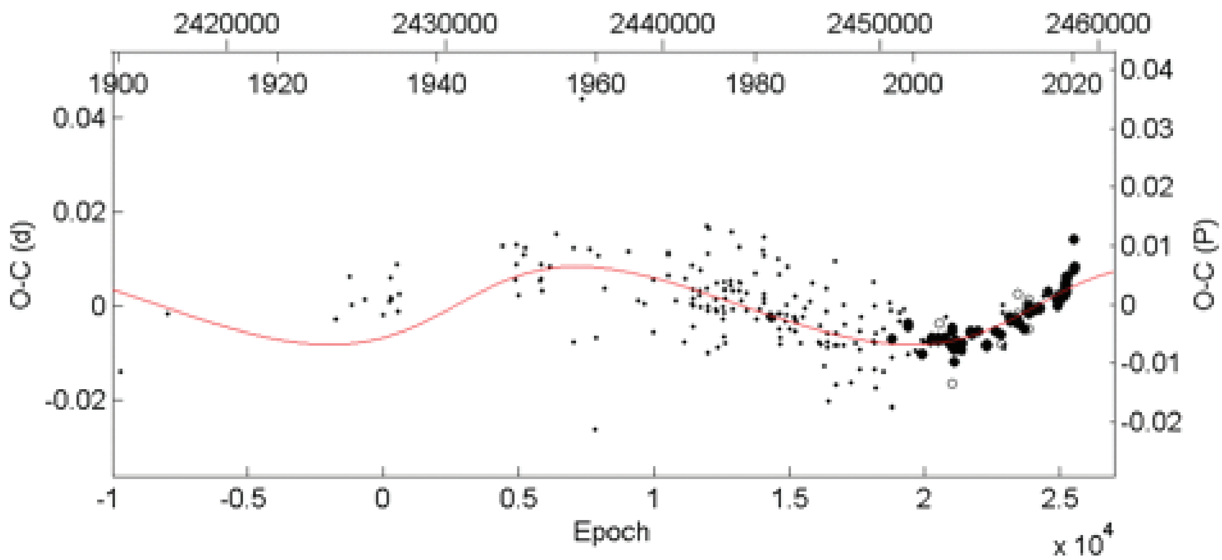

Figure 3. Cyclic change of *O-C* data of AF Gem and its representation by theoretical curve (continuous line) calculated using LITE.

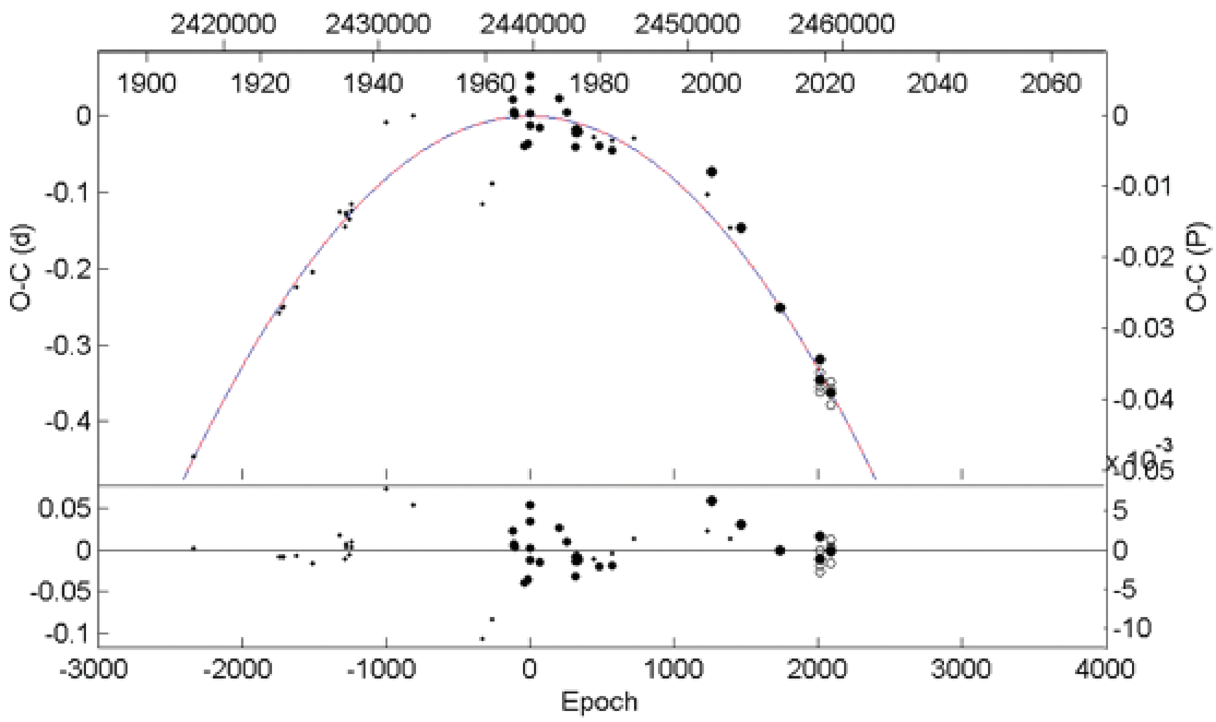

Figure 4. Obtained *O-C* data of RY Gem eclipsing system and the theoretical curve used to represent it and the differences from it (continuous line represents theoretical fit).

4. Conclusion

As a result; this study focused on the orbital period change of semi-detached eclipsing binaries AF Gem and RY Gem. With the analysis made in this study, it makes a significant contribution to the literature in terms of calculating minima times from satellite data and supporting previous *O-C* analysis studies. The orbital periods of the systems are decreasing and the period change rates of AF Gem and RY Gem systems are determined as -0.36 and -55 s/cn. The cause of the sine-like change of AF Gem may be demonstrated by the presence of a possible third component around the binary system (possible third component causes light-time effect). Around AF Gem, the smallest mass of possible tertiary components was found to be 0.24 $M_{\odot}$. For AF Gem and RY Gem, the systems can be better understood by performing *O-C* analysis again with the minima times acquired from the recent observations together with the past minima times. To learn more about the nature of AF Gem and RY Gem, high resolution spectra should be explored.

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Author Contributions

The entire article was made by Muhammed Faruk YILDIRIM (writing, interpretation, analysis, calculation of minima times...).

References

Applegate, J. H., 1992. A Mechanism for Orbital Period Modulation in Close Binaries, Astrophysical Journal, 385, 621. https://doi.org/10.1086/170967

Chambliss, C. R., 1982. AF GEM: An Eclipsing Triple Star. Publications of the Astronomical Society of the Pacific, 94, 926. https://doi.org/10.1086/131086

Erdem, A. and Öztürk, O., 2014. Non-conservative Mass Transfers in Algols. Monthly Notices of the Royal Astronomical Society, 441, 2. https://doi.org/10.1093/mnras/stu630

Gaposchkin, S., 1932. Die Bedeckungsveraenderlichen. Veroff. de Berlin-Babelsberg Sternwarte, 9, 5. https://articles.adsabs.harvard.edu/pdf/1932VeBB....9D...1G

Guthnick, P. and Prager, R., 1928. Siebzehn neue Veränderliche. Astronomische Nachrichten, 233, 35. https://doi.org/10.1002/asna.19282330303

Hall, D. S., Stuhlinger, T. and Wilson, J. W., 1981. UBV Photometry of RY Gem. IAU Archives of unpublished observations of variable stars file number. 86, 1. https://ui.adsabs.harvard.edu/abs/1981IAU27..86....1H/abstract

Huang, S. S. and Struve, O., 1956. The Radii and Masses of Eclipsing Binary Stars. Astronomical Journal, 61, 300. https://doi.org/10.1086/107349

Irwin, J. B., 1959. Standard Light-Time Curves, Astronomical Journal, 64, 149. https://doi.org/10.1086/107913

Kalv, P. V. 1980. Investigation of Selected Long Period Eclipsing Binary Stars Based on Photoelectric Observations, Tartu, PhD thesis manuscript (unpublished thesis).

Kopal, Z., 1959. Close Binary Stars. The International Astrophysics Series, London: Chapman & Hall. https://ui.adsabs.harvard.edu/abs/1959cbs..book.....K/abstract

Kreiner J. M., 2004. Up-to-Date Linear Elements of Eclipsing Binaries. Acta Astronomica, 54, 207-210. https://articles.adsabs.harvard.edu/pdf/2004AcA....54..207K

Kwee, K. K. and van Worden, H., 1956. A Method for Computing Accurately the Epoch of Minimum of an Eclipsing Variable. Bulletin of the Astronomical Institutes of the Netherlands, 12: 327-330. https://articles.adsabs.harvard.edu/pdf/1956BAN....12..327K

Lanza, A. F. and Rodono, M., 2002. Gravitational Quadrupole-moment Variations in Active Binaries. Astronomische Nachrichten, 323, 424. https://doi.org/10.1002/1521-3994

Maxted, P. F. L. and Hilditch, R. W., 1995. The Absolute Parameters of the Algol-type Binary Star AF Geminorum. Astronomy and Astrophysics, 301, 149. https://articles.adsabs.harvard.edu/pdf/1995A%26A...301..149M

Paschke, A. and Brat, L., 2006. *O-C* Gateway, a Collection of Minima Timings. Open European Journal on Variable Stars, 23, 13. http://var.astro.cz/oejv/oejv.php?oejv=23

Pustylnik, I., Kalv, P., Aas, T., Harvig, V. and Mars, M., 2005. Light-Time Effect in Selected Semi-detached and Contact Binaries with Observable Third Components. Astronomical Society of the Pacific, 335, 321. https://articles.adsabs.harvard.edu/pdf/2005ASPC..335..321P

Retter, A., Richards, M. T. and Wu, K., 2005. Evidence for Superhumps in the Radio Light Curve of Algol and a New Model for Magnetic Activity in Algol Systems. The Astrophysical Journal, 621, 417-424. https://doi.org/10.1086/426667

Soydugan, F., Frasca, A., Soydugan, E., Catalano, S., Demircan, O. and Ibanoğlu, C., 2007. A Spectroscopic Study of the Algol-type Binaries S Equulei and KO Aquilae: Absolute Parameters and Mass Transfer. Monthly Notices of the Royal Astronomical Society. 379, 1533-1545. https://doi.org/10.1111/j.1365-2966.2007.12065.x

Sarma, M. B. K. and Vivekananda R. P., 1997. TRY Geminorum - Revised Elements. The Astronomical Journal, 114, 800. https://doi.org/10.1086/118512

Tvardovskyi, D., 2019. Third Components with Elliptical Orbits in the Eclipsing Binaries: AB Cas, AF Gem, AR Boo, BF Vir and CL Aur. eprint arXiv:1911.12415. https://arxiv.org/pdf/1911.12415.pdf

Yang, Y. G., Yang, Y. and Li, S. Z., 2014. Photometric Properties for Selected Algol-type Binaries. VIII. The Triple Systems DI Peg and AF Gem Revisited. The Astronomical Journal, 147, 6. https://doi.org/10.1088/0004-6256/147/6/145

Yuhas, B. J., Reed, P. A. and Chambliss, C. R., 2013. First CCD Photometry of the Interacting Binary AF Geminorum: Evidence for a Gravitationally Bound Third Object? Bulletin of the American Astronomical Society, 45, 8. https://ui.adsabs.harvard.edu/abs/2013giec.conf10103Y/abstract

Zasche, P., Liakos, A., Niarchos P., Wolf. M., Manimanis V., Gazeas K., 2009. Period changes in six contact binaries: WZ And, V803 Aql, DF Hya, PY Lyr, FZ Ori, and AH Tau. New Astronomy 14: 121-128. https://doi.org/10.1016/j.newast.2008.06.002